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Topic A6: Health and Indoor Epidemiology

The Role of Surfaces in the Transmission of Bioaerosols from Source to Patient in Hospital Single and Two-bed Rooms

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INTRODUCTION

Risk of acquiring hospital acquired infections (HCAI) is omnipresent in health-care facilities worldwide and understanding transmission routes is key to effective control. Conservative estimates by Harbarth et al. (2003) show that potentially 20% of infections contracted through contact transmission may be preventable. Several recent studies have highlighted the importance of surface contamination and hinted at a causal link to subsequent patient infection (Bhalla et al., 2004). Pathogens have been shown to accrue on health-care workers' (HCW) hands as they touch surfaces (Pittet et al., 1999) and hence can subsequently be transmitted to patients (Hayden et al, 2008). However, there is currently little robust understanding as to how HCW surface contacts and activities in the health care environment result in patient exposure to such pathogens. Differences in benchmarking of surveillance data often make comparisons difficult on any level, however the significance of the problem is undisputed (Smith et al., 2012).

Aerial dispersion of bioaerosols and subsequent contamination of surfaces has been recognised as a potential transmission route for some of these infections (Bhalla et al. 2004). However the combined role of airborne dispersion, pathogen contamination of hospital room surfaces and interaction with human behaviour is still poorly understood and constitutes an area of much controversy and challenging research. Furthermore the influence of airflow patterns and ward design on the risk is not well understood; single bedrooms are widely advocated for their infection control potential, yet there is little data to quantify the benefits. This research considers the question: Are single-bed patient rooms more effective than their multi-bed counterparts at reducing the risk of infection from environmental contamination? The study combines CFD modelling of particle deposition with a contact risk model framework for quantifying the number of colony forming units (cfu) contaminating HCWs' hands following care in two room types.

METHODOLOGIES

Three mechanically ventilated case scenarios were considered: A single-patient room and a two-patient room where the position of the infectious subject was varied with respect to the inlet diffuser, effectively creating two sub-cases (see Table1 and Figure 1).

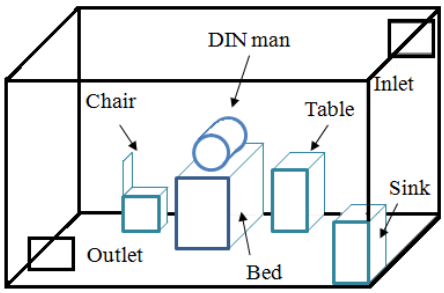
Table 1: Case-study scenarios

Case Nº	**1**	**2a**	**2b**

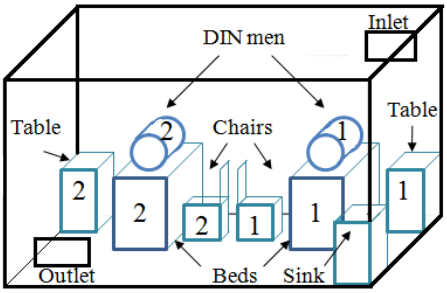
Scenario	Single-bedroom	Two-bed room	Two-bed room
Aerosol release	Patient head	Patient 1	Patient 2

Bioaerosol deposition

Airflow and bioaerosol behaviour was modelled through CFD RANS simulations in Fluent (Ansys v13) using the standard RSM turbulence model. Lagrangian particle tracking of 2.5micron-sized droplets, validated through experiments (King et al. 2013), was used to predict spatial surface distributions of bioaerosol deposition in the single (Figure 1a) and a two-bed room scenarios (Figure 1b). Simulations were based on a comparable experimental set-up. Heated mannequins (DIN-men) were used to represent human patients lying supine on the beds. Ventilation is set to 6 air changes per hour in all cases via wall-mounted inlet and outlet diffusers on opposing façades. Full details can be found in King et al., 2013.



a) Single room set-up



b) Two-bed room set-up

Figure 1. Drawings of room set-up representing hospital single and two-bed rooms (both 2.26m x 3.36m x 4.2m)

Surface contact sequences

Sequences of health care worker surface contacts during typical patient care episodes were determined from an observation study in a community hospital. Care types included: Direct care, Housekeeping, Mealtimes, Medication rounds, Personal care and Miscellaneous care. Over 400 observations were conducted and five surface categories were monitored during each care episode, namely: Within patient reach (Near-patient), out of patient reach (Far-patient), the patient themselves, medical equipment, and hygiene products. All surface categories apart from the patient are considered to be made of hard, non-porous material. Hand hygiene was also recorded for all care types. Data collected was used to create contact frequencies for each surface and care type.

Modelling pathogen accretion

A Monte-Carlo simulation of the mechanics of pathogen transfer from surface-to-hands was developed using the CFD predicted deposition patterns in conjunction with the clinical observation of surface contact sequences. The quantity of pathogens accrued on HCWs hands (Y) during patient care was modelled as a function of the number of surface touched (i=1..n), surface contamination levels (V) and the surface area of skin in contact with the surface (A) (Brouwer et al. 1999). However, it is reasonable to assume that not all of the pathogens in contact with the surface area of skin touching the surface are transferred. Therefore a transfer efficiency (λ) is defined to represent the proportion of pathogens that are transferred in the

upward direction (Rusin et al. 2002). During hand-to-surface contact it is equally reasonable to assume that some quantity of pathogens already acquired (βY) are deposited from the hand onto the surface during a contact (Rusin et al. 2002). However this quantity deposited will depend on the current hand inoculum level (Y_{i-1}). Therefore this model will consider transfer in both directions or bi-directional transfer. Consequently pathogen accretion (Y) can be modelled by means of a recurrence relationship given in equation 1.

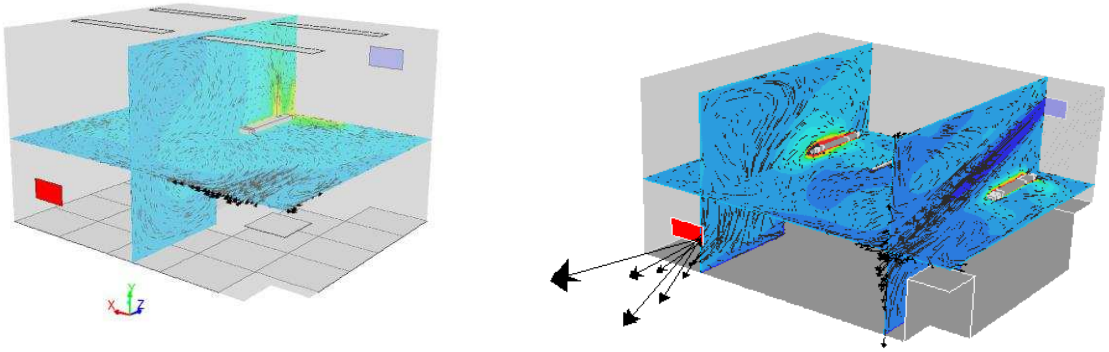
$$Y_i = \lambda_i V_i A_i + \beta_i Y_{i-1}, \quad \textbf{(1)}$$

This was used to predict the number of pathogens (cfu) on HCWs' hands as they perform the observed routine patient care in the two rooms. Hand hygiene is included by assuming that a certain number of pathogens are removed after care concludes according to observations and experiments by Girou et al. (2002). For each scenario 1,000 simulations were conducted to produce a distribution, and the model validated against available literature (Pittet et al. 1999).

RESULTS AND DISCUSSION

Bioaerosol deposition

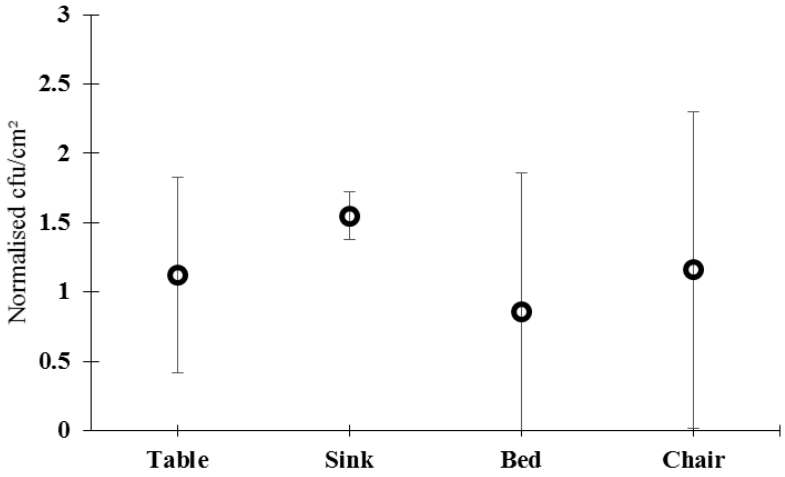
Figures 2a and b) show simulated temperature contours and velocity vectors for the single and two-bed patient rooms, plotted on the horizontal and vertical surface through the bed. Complex flow structures can be observed, with the cold inlet air impinging on the opposite wall and multiple recirculation zones at the foot of the bed. A vertical heat plume emanates from the supine mannequin and is depicted in the vertical plane.



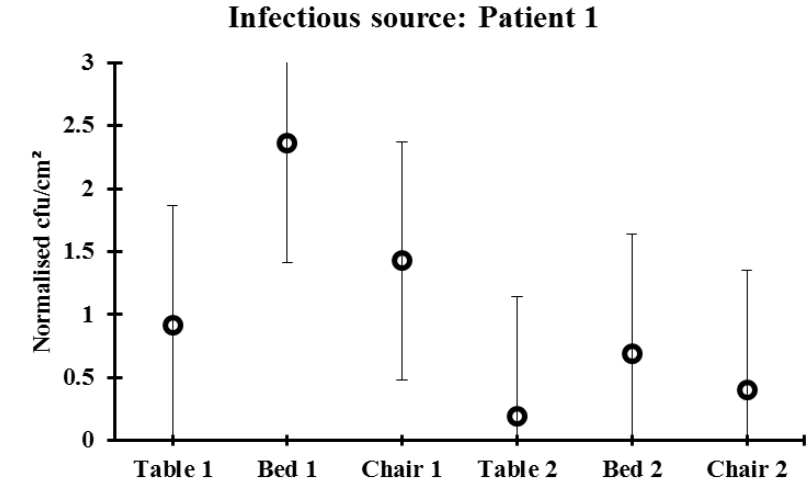
a) Single room b) Two room

Figure 2. Velocity vectors (0.001-0.1m/s) superimposed over temperature contours (22-37ºC)

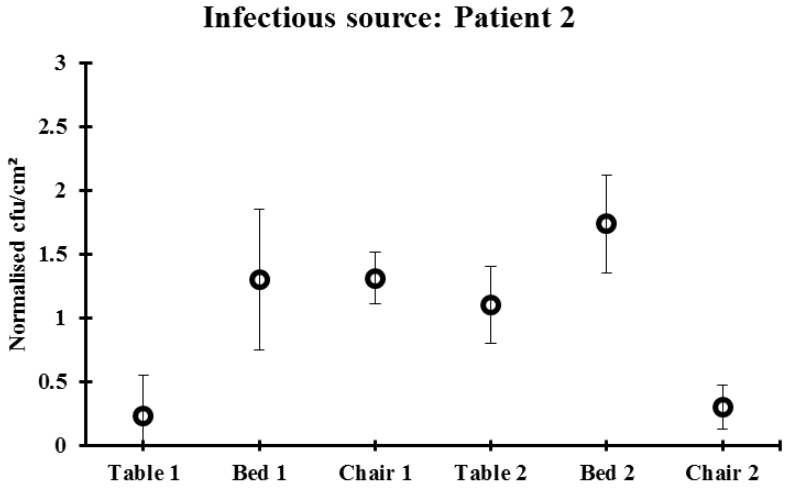
Figures 3 a) and b) depict the predicted pathogen concentrations in the three scenarios normalised with respect to the global average. In the two-bed room cases, when patient 1 is the infectious source, bioaerosols have a tendency to disperse, contaminating the adjacent surfaces to patient 2. Conversely no such marked trend is observed when patient 2 is infectious, where the particles are likely extracted by the ventilation rather than deposited on far away surfaces.



a) Scenario 1: Single-bed room



b) Scenario 2a: Two-bed room, infectious patient: 1



c) Scenario 2a: Two-bed room, infectious patient: 2

Figure 3. Predicted surface colony forming units/cm^2 based on room type, normalised with respect to global average.

Clinical observations

Figure 3 shows surface contact distributions categorised by care type, which exhibit a strong influence on the HCWs' movements. Care types could not be distinguished with respect to the frequency of patient contacts; however environmental surface contacts exhibited a statistically significant variation.

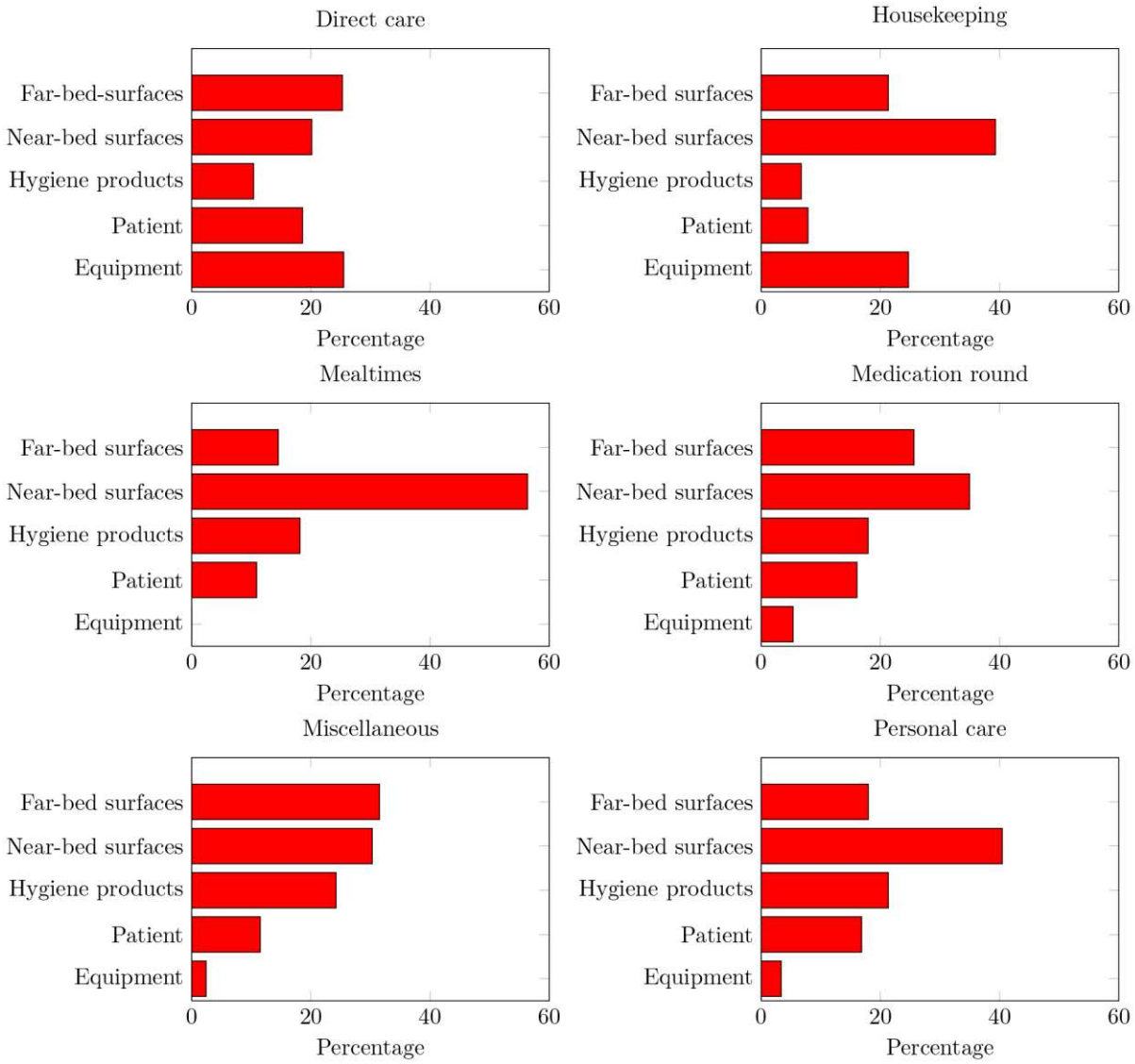


Figure 3. Surface contact distribution subdivided by care type

Pathogen accretion

Figure 4 shows box-plots representing the predicted HCW's hand contamination levels for the six care types for all three room scenarios. Contamination (Y) values have been normalised with respect to the mean contamination levels of the HCWs after direct care in the single-bed room to enable comparison between rooms and care. Single rooms results are consistently lower than their two-bed room counterparts. Pick-up of pathogens during housekeeping appears to be highest in all scenarios, with mealtimes the lowest, reflecting the different likelihood of contact with surfaces during these two activities. The results for the two-bed scenarios show that spatial deposition of particles and subsequent accretion by HCWs is

influenced by the location of the ventilation supply inlet relative to the source. Locating a susceptible patient closer to the supply air is likely to reduce the risk of environmental contamination due to bioaerosol release from a neighbouring infectious patient.

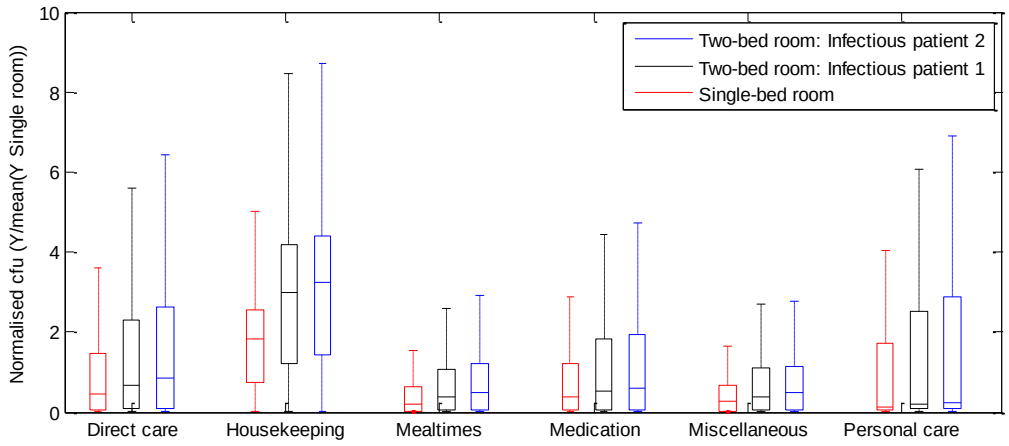


Figure 4. Predicted colony forming units on HCWs hands after each type of patient care.

CONCLUSIONS

Results demonstrate that hand colonisation is likely to depend on care type, room layout and in particular on the spatial distribution of pathogens between surfaces, which is influenced by ventilation strategy. Contamination on the HCWs' hands after patient care in a single-bed room, even after hand hygiene, is by no means negligible. However during care within the two-bed room colonisation levels are significantly higher throughout due to the spatial spread of microorganisms into the zone of the neighbouring patient. Positioning infectious patients within an unobstructed path between the inlet and outlet diffuser significantly reduces cross contamination to other patients surfaces (Two-bed room: Infectious patient 1).

Results indicate that colonisation levels of HCWs' hands are likely to be significantly lower after care in single patient rooms than after care in a two-bed room and that patient positioning and ventilation design is important in helping curtail the risk of infection transmission.

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